Doppler radar and lidar observations of a thunderstorm outflow

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1. Introduction

Over the last thirty years or so radar has enabled study of the strong downdraughts from thunderstorms which move laterally when they reach the ground (for a review see for example Cotton and Anthes, 1989). The cold air flow, often referred to as a density current, from these downdraughts produces a gust front within the lowest few hundred metres of the atmospheric boundary layer, which propagates away from the thunderstorm. The outflow has been modelled in both the laboratory (see for example Simpson, 1987), and numerically (see for example Droegemeir and Wilhelmson, 1986).

Convergence at the leading edge of the outflow may lead to the initiation of further storms as the outflow interacts with pre-existing cumulus clouds (Moncrieff and Miller, 1976; Weismen and Klemp, 1986; Wilson and Megenhardt, 1997). The parameter Δu , the low level shear directed normal to the convergence line and the relative cell speed, are highly correlated, and relate to whether conditions are favourable or not favourable for further storm development. Wilson et al (1998) discuss such conditions noting that large Δu and deep updraughts are favourable conditions with storms moving at a speed similar to the gust front. In unfavourable conditions the storms move in a direction opposite to the gust front direction, and Δu increases with height giving a negative value and shallow tilted updraughts.

Martner (1997) was able to measure vertical velocities in a thunderstorm gust front and outflow using a 3.2 cm wavelength (X-band) Doppler dual polarisation radar in vertical pointing mode. The spatial resolution of the measurements was 112 m in range by 30 m wide, and a new beam of data was obtained every 0.3 sec. Unfortunately the horizontal wind profiles were not measured. An arc cloud was seen above the gust front at 3.8 km AGL. The extremes of vertical velocity ranged from + 9.7 m/s at 1.35 km AGL to – 9.9 m/s at 1.46 km AGL one minute later. The up- and downdraughts in excess of 2 m/s each lasted for about 2 minutes.

In the present study scanning Doppler lidar measurements of a thunderstorm outflow were made on the 12 August 2007 at Achern in the Rhine Valley, Germany. The lidar measurements have a spatial resolution of 30 m in range by approximately 1 m wide with a temporal resolution of 0.1 sec. The storm context of the outflow is provided by the DLR Doppler dual polarisation C-band radar (POLDIRAD) located at Waltenheim-sur-zorn about 36 km to the north west of Achern. Both instruments were operated during the international Convective and orographically-Induced Precipitation Study (COPS) Experiment.

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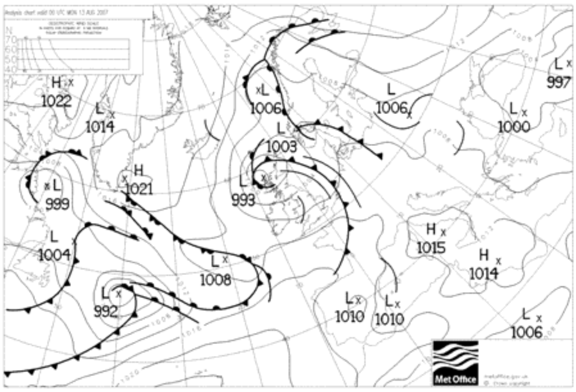


Fig. 1: Synoptic chart at 00UTC 13 August 2007

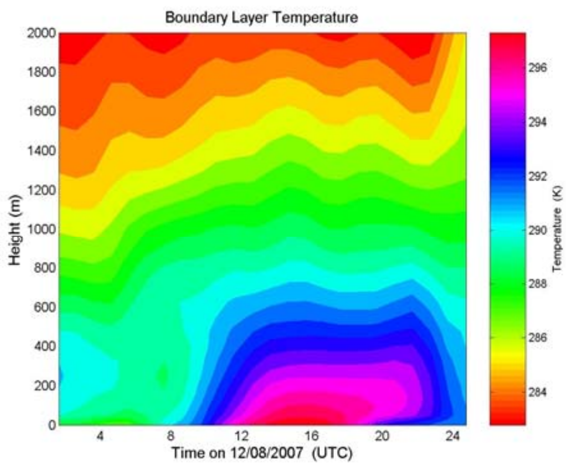


Fig. 2: Height – time series of temperature derived from a scanning microwave radiometer at Achern on 12 August 2007

2. Synoptic situation

A low pressure area centred over northern Scotland moved towards Scandinavia with a trailing cold front moving across the Low Countries and eventually into Germany (Fig. 1). The cold front released instability ahead of it inducing thunderstorm development over southern Germany. A surface based scanning microwave radiometer at Achern operated by the University of Salford showed an inversion between 19 and 22 UTC, which inhibited the convective development during this period (Fig. 2). The approaching cold front eroded this inversion, and thunderstorms developed over the western edge of the Rhine Valley moving into the Valley towards the north east.

3. Radar observations

The POLDIRAD radar shows convective cells developing to the west and north west of Achern. The cells moved from the mountains over the Rhine Valley. An outflow from the most intense cell (Fig. 3) can be seen moving towards Achern. The thunderstorm cell reaches about 10 km altitude (Fig. 4a), but then collapses to about 5 km (Fig 4b) some 20 minutes later as the outflow moves away from the cell. This is consistent with a downburst (for example Weisman and Klemp, 1986). Unfortunately the details of the outflow on the radar RHIs are not clear, and there is some confusion with ground clutter from the Hornisgrinde mountain chain on the eastern side of the Valley.

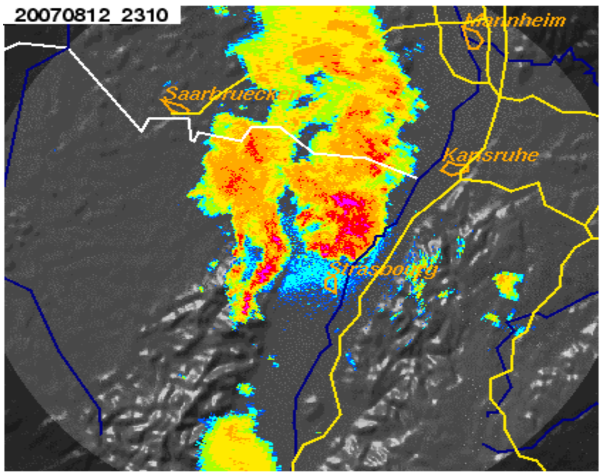
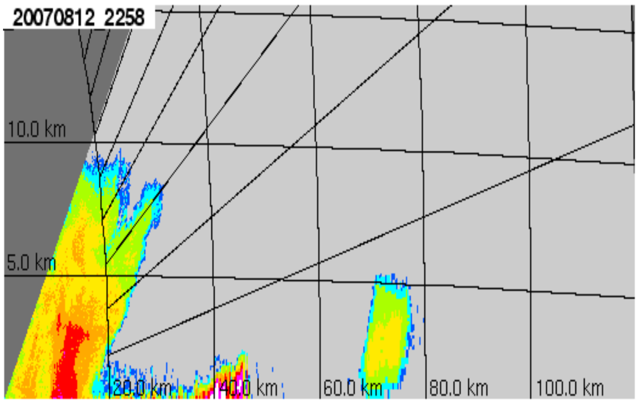
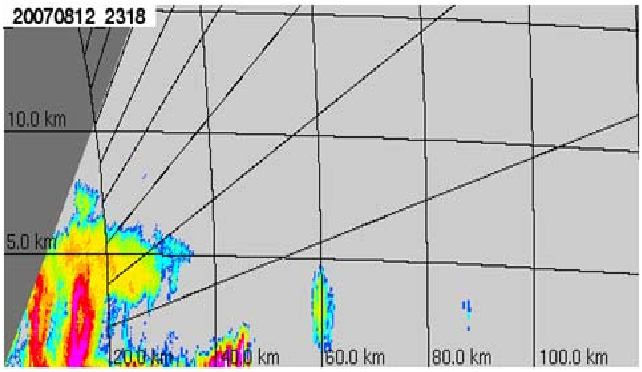


Fig. 3: POLDIRAD radar PPI AT 2310 UTC 12 August 2007



(A)



(B)

Fig. 4: POLDIRAD radar RHIs on 12 August 2007 at (A) 2258 UTC and (B) 2318UTC

4. Lidar observations

The University of Salford 1.5 micron scanning Doppler lidar was located at Achern. Just after 23 UTC the lidar observed the thunderstorm outflow (Fig. 5). All the characteristics of a density current flow are evident. Strongly ascending motion of several metres per second alternated with comparable descending motion, which gets weaker as the outflow moves through. The feature is about 800 m deep and a cap cloud is observed at the leading edge. As the outflow moves through about a one degree Celsius drop in temperature at the surface was observed at Achern.

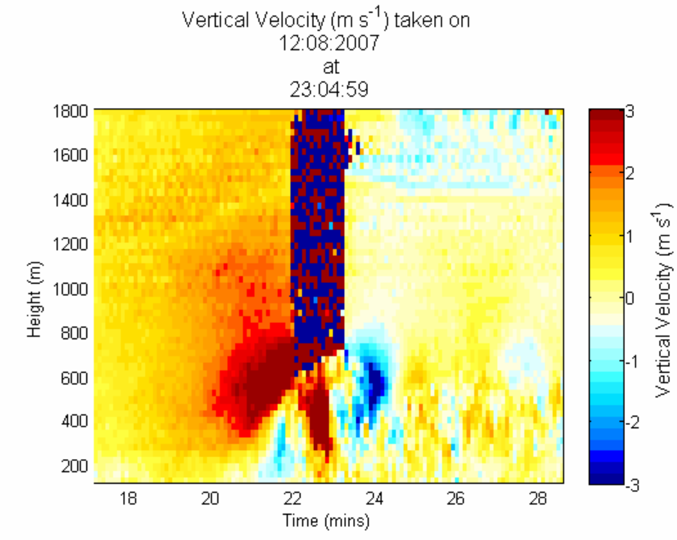


Fig. 5 :Doppler lidar height – time plot of vertical velocities (metres per second) starting at 2305 UTC on 12 August 2007 at Achern

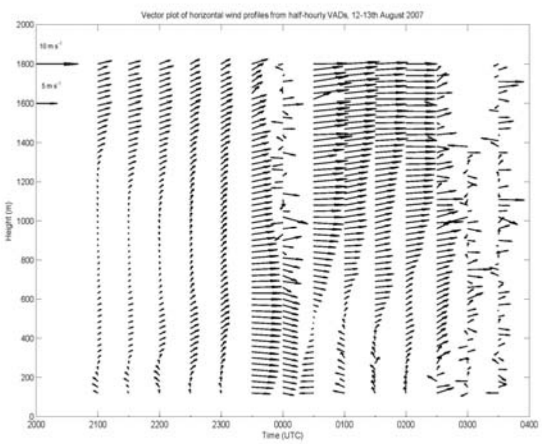


Fig6: Vertical profiles of horizontal wind velocity before, during and after the passage of the thunderstorm outflow derived from Doppler lidar at Achern

As well as producing backscatter and vertical velocity measurements the lidar automatically carried out Velocity Azimuth Display (VAD) scans every half hour. Horizontal wind profiles were constructed (Fig. 6) showing considerable convergence as the outflow leading edge moves over Achern. The values of Δu observed suggest that conditions are not favourable for subsequent cell development (section 1). The storm cells were moving at almost 90 degrees from the direction of movement of the outflow.

The observed vertical velocities are about half the magnitude of those reported by Martner (1997), and the Achern outflow was also much shallower. However, significant kinetic energy dissipation is observed. Fig. 7 shows the kinetic energy dissipation rate estimated using the lidar processing technique described by Davis et al (2004). Note the large increase as the nose of the outflow passes through Achern, an increase of about a factor of almost ten.

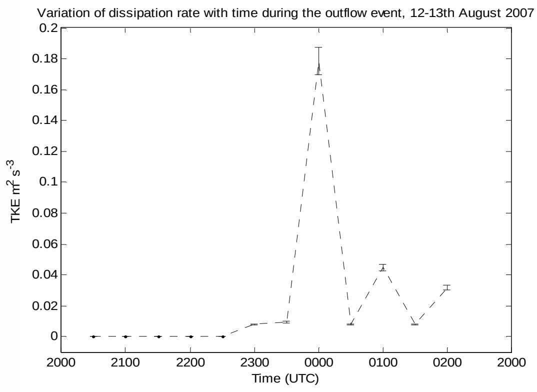


Fig. 7:Time series of kinetic energy dissipation rate derived from Doppler lidar before, during and after the passage of the thunderatorm outflow at Achern

5. Concluding remarks

The lidar and radar data complement each other in showing how the thunderstorm outflow is formed and moves away from the main cell area. Comparison of these measurements with those made previously in the USA using a X-band radar indicate that the Achern event is shallower with vertical velocities of up to about half the maximum values measured in the USA event. However, there is significant wind shear and kinetic energy dissipation in the Achern event close to the ground suggesting that such outflows could be a severe hazard to aircraft landing and taking off.

Acknowledgement

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